A TERRESTRIAL ANALOG FOR CARBONATES IN ALH 84001: ANKERITE-MAGNESITE CARBONATES IN MANTLE XENOLITHS AND BASALTS FROM SPITSBERGEN (SVALBARD), NORWAY.

Allan H. Treiman[1], Dmitri A. Ionov [2], Hans E.F. Amundsen [3], Ted Bunch[4], and David F. Blake[4]. [1] Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston, TX 77058. [2] School of Earth Sciences, Macquarie University, Sydney NSW 2109, Australia. [3] Saga Petroleum AS, N1301 Sandvika, Norway. [4] Exobiology Branch, NASA Ames Research Center, Moffett Field CA 94305.

Mantle xenoliths and their host basalts from the Spitsbergen archipelago (Norway) contain chemically zoned globules and patches of ankerite - magnesite carbonate (AMC) minerals that are similar to the carbonate minerals of ALH 84001. The Spitsbergen AMC formed during and/or after eruption of the basalt and xenoliths, and may be associated with replacement of primary minerals in the xenoliths. These carbonate globules may help shed light on the origin of ALH 84001 carbonates. At this point, the Spitsbergen ankerite-magnesite carbonates are so little studied that their mode of formation is not clear.

Introduction. The origin of the carbonate minerals in ALH 84001 was controversial [1,2], and is more so since [3] proposed that they are associated with ancient martian biota. A difficulty in understanding these martian carbonate minerals has been the lack of comparable terrestrial occurrences for comparison. Here, we report a terrestrial analog: strongly zoned ankerite-magnesite carbonate globules in mantle xenoliths and basalts from Spitsbergen (Svalbard), Norway.

Samples and Methods. Sample of basalt and mantle xenoliths are from the collections of H.E.F.A. and D.A.I. from quaternary-age basanitic volcanics of northwest Spitsbergen [4-9]. Most of the xenoliths are spinel lherzolites, ± minor amphibole, phlogopite, apatite, and/or dolomitic to Mg-calcitic carbonates [4-9]. Many xenoliths were partially melted, and contain partially crystallized patches of vesicular silicate glass (not host basanite), typically surrounding spinels. Quenched carbonate liquids may be present as ocelli in the silicate glass and elsewhere [4,8,9]. Thin sections were examined optically and with BSE imagery. Chemical compositions were acquired by EMP at low beam current (4 - 10 nA).

Ankerite-Magnesite Carbonates. Many xenoliths and basalt samples contain globules and patches of ankerite-magnesite carbonates (AMC for short), ranging from ~ 10 to > 100 µm across [4,8,9]. The AMC are common in areas of silicate±carbonate melts, but can be abundant as thin fracture-fills (i.e., pancakes [3]), as partial fillings of vesicles, along grains boundaries associated with silicate glass, and as replacements of olivine (Figs. 1,2). Almost all AMC are concentrically zoned in color and composition: cores are ferroan ankerite or calcian siderite and rims are nearly pure magnesite (Tab. 1). In most AMC, the concentric zoning consists of alternating sub-micron bands of ferroan and magnesian carbonate (Fig. 1). A few AMC have linear (not concentric) zoning, seemingly parallel to vein boundaries. The sizes, abundances, and detailed stratigraphies of the AMC are different in each xenolith or basalt fragment.

Fine-grained silica is common as thin coatings (~5 µm) around AMC, as botryoidal or stalactitic masses in AMC (Fig. 1), and also lining the walls of open fractures . Many AMC are intimately mixed with unidentified silicates, possibly could be fine-grained silica or phyllosilicates. Rare dark grains in the magnesitic portions of AMC could be magnetite, but there are no magnetite rich layers as in the ALH 84001 carbonate globules.

Pockets, vesicles, veins, and fractures in some of the xenoliths and the basalts that host them may also be filled with nearly structureless masses of magnesian saponite clay (Tab. 1; Fig. 1). These are very common in some samples. When AMC and clay are both present, the AMC and their silica coatings are nearly always between the clay and the host materials.

Carbonate Compositions. A typical globule is cored with ankerite or siderite, and grades outward through a complex series of fine layers to nearly pure magnesite (Figs. 1,2). The core material of the AMC seems to vary among xenoliths - some have ferroan ankerite, while others have calcian siderite (Fig. 3). In both cases, the EMP chemical compositions (which may integrate over many submicron bands) show a continuous trend toward calcian magnesite and then non-calcian magnesite (Fig. 3).

Origin of Ankerite-Magnesite Carbonates. The AMC formed during or after solidification of the host basalts, because the AMC occur in vesicles in the basalts, and are localized along fractures cutting basalt glass. Thus, the AMC must have formed near the Earth's surface, probably within the volcanic edifices or deposits. We cannot rule out, at this point, that the AMC replaced a mantle-derived carbonate precursor material. In some places, AMC grade continuously into magnesite that appears to be an isovolumetric replacement of olivine.

The AMC are not associated with devitrification of silicate glasses. Presence of magnesite rather than hydromagnesite suggests temperatures above ~0°C.

Implications for ALH 84001. These ankerite-magnesite globules from Spitsbergen are the first publicized example of Earthly carbonates similar in structure and chemistry to those in ALH 84001. It will now be possible to study the full geological settings of carbonates similar to those in ALH 84001, without the overprinting of a long subsequent history [10].

However, the Spitsbergen AMC may not have formed exactly as did the carbonates of ALH 84001. The AMC and ALH carbonates differ in the details of their internal zoning, the presence of magnetite and pyrite, and mode of emplacement (mostly space filling vs. mostly replacement [10]). More complete data, including stable isotope abundances, will help elucidate the formation mechanisms of the AMC and their applicability to ALH 84001.

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[1] Romanek et al. *Nature* **372**, 655 (1994). Treiman A.H. *Meteoritics* **30**, 294 (1995). [2] Mittlefehldt D.W., *Meteoritics* **29**, 219 (1994). Harvey R.P. & McSween H.Y.Jr. *Nature* **382**, 49 (1996). Scott E.R.D. et al. *Nature* **387**, 377 (1997). [3] McKay et al. *Science* **274**, 2123 (1996). [4] Amundsen H.E.F. *Nature* **327**, 692 (1987). [5] Amundsen H.E.F. et al. *Tectonophysics* **139**, 169 (1987). [6] Skjelkvåle Brit-L. et al. *J. Volcanol. Geotherm. Res.* **37**, 1 (1989). [7] Vågnes E. and Amundsen H.E.F. *Geology* **21**, 251 (1993). [8] Ionov D.A. et al. *Earth. Planet. Sci. Lett.* **119**, 283 (1993). [9] Ionov D.A. et al. *Contrib. Mineral. Petrol.* **125**, 375 (1996). [10] Treiman A.H. *Meteoritics* **33,** in press; *Lunar Planet. Sc***XXIX**, this volume.

Table 1. EMP Chemical Analyses

	SX-3 A1 core	SX-3 A2 core	SX-3 A2 rim	SB-4 c1 core	SB-4 clay
SiO_2	1.15	0.34	0.16	0.10	57.06
TiO_2	n.d.	0.05	0.00	n.d.	0.03
Al_2O_3	n.d.	0.00	0.01	n.d.	0.03
Cr_2O_3	n.d.	0.07	0.03	n.d.	0.00
FeO	29.28	14.76	5.58	33.71	3.98
MnO	0.71	0.39	0.09	0.49	0.03
MgO	5.45	13.91	43.61	13.02	20.03
CaO	21.08	25.30	0.13	9.08	0.32
Na_2O	n.d	0.06	0.13	n.d.	0.07
K_2O	n.d.	0.00	0.01	n.d.	0.13
CO_2	40.88*	44.33*	51.20*	42.30*	n.d.
Sum	98.55	99.21	100.95	98.70	81.67

* By stoichiometry with Fe, Mn, Mg, Ca.

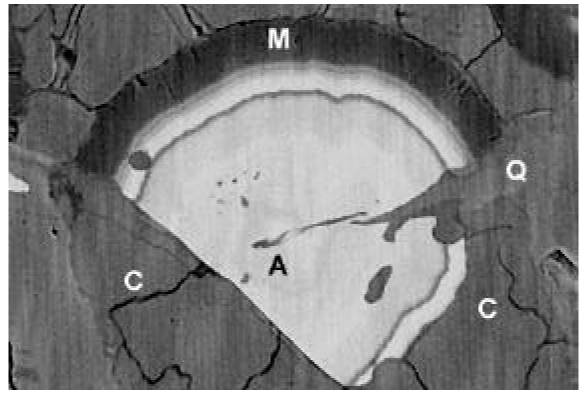

Fig. 1. BSE image of ankerite-magnesite carbonate globule (AMC) in xenolith SB-4. Core is ankerite (A); rim is magnesite (M) AMC is surrounded by silica (Q) and by saponite clay (C). 215 µm across.

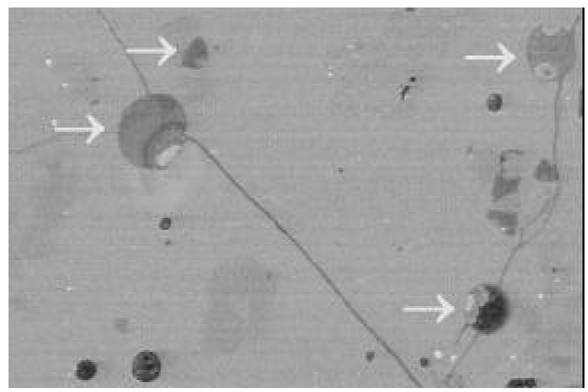

Fig. 2. BSE image of AMC (arrows) filling vesicles in basalt surrounding xenolith SB-4. 454µm across.

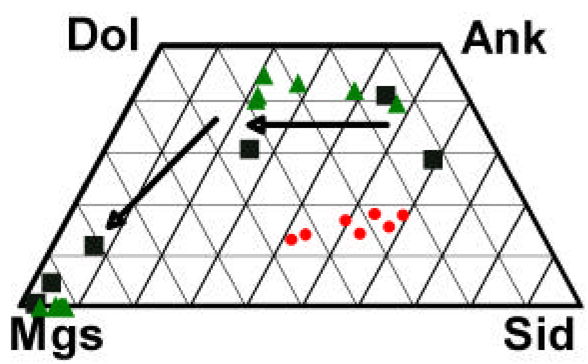

Fig. 3. Triangular diagram: chemical compositions of carbonate minerals in two AMC globules. Arrows point core to rim. Triangles and squares - SX3; circles SB4.